MISSOURI RIVER

SIOUX CITY, IOWA TO RULO, NEBRASKA

POTAMOLOGY INVESTIGATION

A STUDY OF THE SHIFT IN THE STAGE-DISCHARGE RELATIONSHIP OF THE MISSOURI RIVER AT SIOUX CITY, IOWA

PREPARED BY
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Over the past 10 years, the Missouri River has experienced a large downward shift in its stage-discharge relationship at the Sioux City, IA, gaging station. The stage for a given discharge, in the range of 19,000 to 40,000 cfs, has decreased 5-8 feet in this time. A study of related data shows that the combined interaction of geologic, hydrologic, geometric, and hydraulic factors influenced this change.
The major changes which combined to cause a general degradation in the river reach near Sioux City include a reduction in suspended sediment load, a shortening of the river channel in the area, construction of river training works and a recent (7 year) increase in the mean yearly flows as well as increased total channel area below the high bank elevation have lowered the stage for a given discharge at Sioux City. This study illustrates the changes which have occurred in the river since 1950.

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SYLLABUS

Over the past 10 years, the Missouri River has experienced a large downward shift in its stage-discharge relationship at the Sioux City, Iowa, gaging station. The stage for a given discharge, in the range of 10,000 to 40,000 cfs, has decreased 5-8 feet in this time. A study of related data shows that the combined interaction of geologic, hydrologic, geometric, and hydraulic factors influenced this change.

The major changes which combined to cause a general degradation in the river reach near Sioux City include a reduction in suspended sediment load, a shortening of the river channel in the area, construction of river training works, and a recent (7 year) increase in the mean yearly flows as well as increased peak flows. The resulting degradation and increase in total channel area below the high bank elevation have lowered the stage for a given discharge at Sioux City. This study illustrates the changes which have occurred in the river since 1950.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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PURPOSE

The purpose of this study is to identify the revelant data - such as construction, stream morphology, and trends of tributaries - to the observed chronologic changes in river stage of the Missouri River at the Sioux City, Iowa area during the approximate period of 1954-1974. The causal relationships present for the observed effects are to be determined and recommendations are to be made for any further data requirements.

The investigation includes a study of the following data:

a. Missouri River Stage - Discharge Measurements at Yankton, Sioux City, Decatur, and Omaha.
b. Yearly water surface profiles of the Missouri River; Ponca to Omaha.
c. Channel cross-sections at Sioux City, Iowa.
d. Channel Relocation and Mainstem Dam Construction History
e. Missouri River Mileage Data
f. Missouri River Flow Records
g. Suspended sediment measurements at Yankton, S. Dakota, Sioux City, Iowa, and Omaha, Nebraska.

DESCRIPTION

The Missouri River is a dynamic system which is continually altering its position and shape as a consequence of hydraulic forces acting on its bed and banks. These forces result from: (1) geological factors, including bed material, bank material, and soil conditions; (2) hydrologic factors including changes in water and sediment discharge and the hydrologic effects of changes in land use; (3) geometric characteristics of the stream in which a braided natural channel is changed into a single sinuous channel; and (4) hydraulic characteristics such as flow depth, channel slope, and flow velocity. Natural or man-made changes in the above factors, either local or at a distance, can subsequently cause changes in the system which can be propagated for long distances both up and down the stream.

The changes which have occurred in the stage-discharge relationship of the Missouri River at Sioux City, Iowa, are a result of both local and remote changes of the factors mentioned. This study inspects the specific channel modifications in the river reach between Gavins Point Dam and Omaha, Nebraska, which have a bearing on the stage-discharge relationship at Sioux City, Iowa.

The change in the stage-discharge relationship at Sioux City is illustrated in Figure 1, which shows the resulting stage, as measured from an MSL datum, for given discharges over the last 45 years. The large shift in stage which has occurred since approximately 1960, and the increased rate of change beginning in 1967 as seen in the Figure, are the focus of this study.

The history of the stage-discharge relationship as depicted in Figure 1 provides some insight into the factors which have influenced the relationship. One noticeable fact is that a similar drop in stage occurred from 1930 to 1944. This time frame coincides with a major channel realignment period as does the stage change beginning in 1958. From 1945 to 1952 the stage-discharge relationship experienced a stable period during which no major construction occurred. Following 1952 until around 1960, the stage values increased. This rising follows the construction of Randall and Gavins Point Dams. The 1952-1960 period had relatively low mean yearly discharges at Sioux City, Iowa, as seen in Table 6. The low discharges, coupled with degradation below Gavins Point Dam and subsequent deposition farther downstream, could

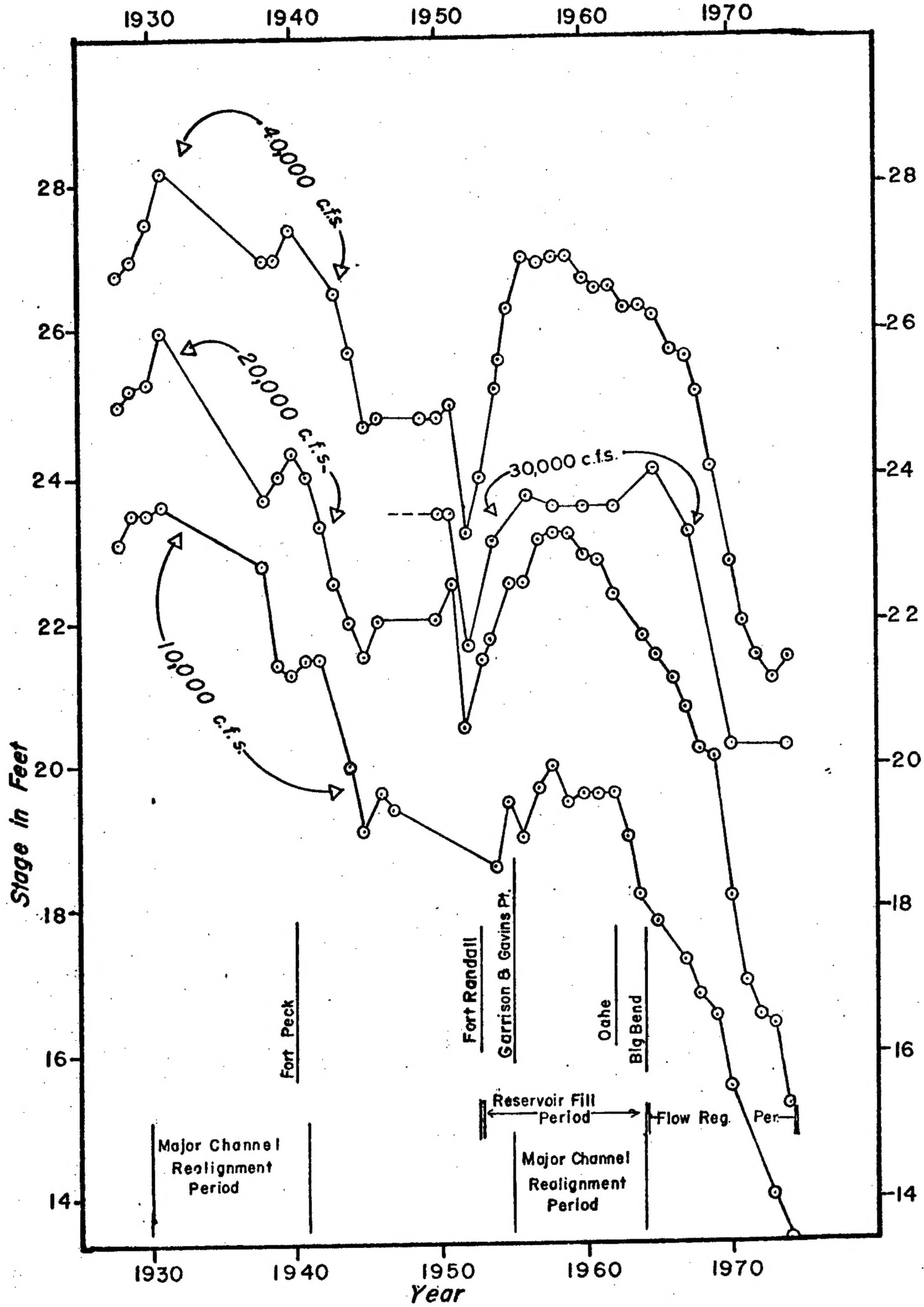

Figure 1. STAGES FOR CONSTANT DISCHARGES, MISSOURI RIVER AT SIOUX CITY, IOWA

account for the rising of the stages at Sioux City from 1952-1960 shown in Figure 1. The period from 1960 produced a dropping stage for a constant discharge with an increase in the rate of drop beginning around 1969. The drop for this period occurred in the presence of major channel realignment and increased mean yearly flows shown in Tables 6-8.

The trends in the stage-discharge relationship have been similar for a wide range of channel discharges (10,000-40,000 cfs), so the change in the relationship for all discharges should be similar and due to the same factors. The parameters influencing the shift in the stage-discharge include both natural and man-made changes in the river morphology, changes in sediment transport capability, changes in availability of sediment supply to the reach, and a change in the runoff characteristics in the basin. The changes in these parameters which influenced the Missouri River rating at Sioux City since 1950 are studied and presented in the following paragraphs to illustrate the causal relationships involved in the shift of the rating.

CHANNEL MODIFICATION HISTORY

The changes made in the channel of the Missouri River have produced significant changes in the river geometry, both locally at Sioux City and also upstream and downstream of this point. Since 1930, the channel has been altered from an unstable braided channel to a single sinuous channel. Major modifications in the channel first began in 1930 and ended in 1941 as seen in Figure 1. The river channel was "left to itself" during WWII when maintenance was at a minimum. Another large channel modification period began in 1952 which had a large effect on the geometry of the river.

Available river mileage data taken from the Missouri River Project Maps indicate that the length of the river channel from mile 732.3 to 619.0 (1960 mileage) has been reduced 11.7 miles in the period 1941-1975 and 10.6 miles in the period 1955-1975 (see Table 1). This represents about a 9 percent change in channel length since 1955. The changes in the channel established a uniform channel width between 600 and 700 feet for the reach from Sioux City to Omaha. In most channel areas, this reduction was 300 to 400 feet less than the width of the existing channel.

Most of the channel realignment and training work was done during the period between 1954 and 1964 which is considered to be a major construction period on the

1941 (mileage as indicated on 1955 map)		1955 (measured from 1955 map)		1960	
Reach	Miles	Reach	Miles	Reach	Miles
760 - 754	6		6.1	732.3-726.2	6.1
754 - 729	25	N/A	25.8	726.2-701.6	24.6
729 - 722	7		7.2	701.6-694.4	7.2
722 - 706	16		15.1	694.4-681.9	12.5
706 - 693	13		13.0	681.9-668.5	13.4
693 - 686	7		6.6	668.5-662.7	5.8
686 - 675	11		10.9	662.7-652.7	10.0
675 - 671	4		4.6	652.7-648.8	3.9
671 - 656	15		13.8	648.8-640.2	8.6
656 - 635	21		20.8	640.2-619.0	21.2
Total length	125 miles		123.9 miles		113.3 miles

TABLE 1. MISSOURI RIVER MILEAGE

Missouri River. Much of the effect of the shortening would arise in these years. Table 2 shows the dates of completion of the cutoffs between Sioux City and Omaha. Figure 2 gives a reference to the location of these bends. The cutoffs near Sioux City, which would influence the rating curve shift, would be those in the reach from the Dakota bends to the Louisville bends, all of which were completed between 1959 and 1965.

Another construction period which directly influenced the rating at Sioux City occurred between 1963 and 1965 when the channel on the Upper and Lower Sioux and Floyd bends was narrowed. This is discussed in the following section.

The construction of several dams on the Missouri River channel also influenced the flow characteristics in the channel near Sioux City. The most influential is Gavins Point dam located approximately 79 river miles upstream of Sioux City. Table 3 gives the dam construction chronology on the Missouri River.

CHANNEL CROSS SECTION CHRONOLOGY NEAR SIOUX CITY, IOWA

The channel cross section history of the Missouri River near Sioux City, Iowa is available at three cross sections. Figures 3 through 5 show the channel cross section for the years 1952, 1961, 1967, 1971, 1973, and 1974 at River Miles 731.7, 731.49, and 727.9 (excluding 1973 in Figure 5). Figure 6 is a location map for these points. Each cross section is plotted in reference to a constant water surface elevation to observe degradation tendencies at Sioux City over the years. The cross sections show that in the years between 1961 and 1967 the channel top width was narrowed approximately 210 feet at mile 731.7, 330 feet at mile 731.49, and 457 feet at mile 727.9 (1960 mileage). These figures represent an average reduction in top width of 32 percent. The narrowing was actually done in the period 1963-1965 by lengthening the dike field and inserting additional dikes between the existing ones.

Another change in the channel was experienced in the period from 1952-1961. Figures 3 through 5 show that a general rise in bed elevation occurred during the years just after construction of Gavins Point dam. The cross sectional area was also greatly reduced in the period from 1952-1961. Figure 7 shows the values of cross-sectional area for the cross-sections previously mentioned.

The data show that the 1952 flood scoured out the

BEND (downstream from Sioux City)	DATE OF COMPLETED REALIGNMENT
Upper & Lower Sioux	Alignment essentially the same in 1950 as now. Channel narrowed 1962-65
Floyd	Same as above
Upper Dakota	Present alignment completed by 1959
Lower Dakota	Present alignment completed by 1959
Omadi	Flow established in present channel in 1961
Upper Browers Lower Browers	The proposed realignment combined the 2 bends into one as of 1954. This alignment was completed in 1959
Snyder	Flow established in present channel in 1961
Upper Glovers Lower Glovers	Combined to one bend - flow established in present channel in 1962
Winnebago	Flow established in 1962
Upper Omaha Mission Middle Omaha Mission Lower Omaha Mission	Little alignment change made. Flow through present alignment began in 1959
Upper Manona Middle Manona Lower Manona	Changed to Upper & Lower Manona in 1954. Diversion completed in 1957

TABLE 2. CHANNEL ALIGNMENT HISTORY BETWEEN SIOUX CITY & OMAHA

BEND (downstream from Sioux City)	DATE OF COMPLETED REALIGNMENT
Upper Blackbird Lower Blackbird	Changed and diverted to only one, Blackbird bend, in 1957
Tieville	Flow established in 1955
Upper Decatur	Flow established in 1955
Middle Decatur	Flow established in 1961
Lower Decatur	Flow established in 1962-1963
Upper Louisville	Flow established in 1965
Lower Louisville	Flow established in 1966
Upper Blencoe Middle Blencoe Lower Blencoe	Present alignment essentially done by 1960. Some structures added since 1960.
Upper Little Sioux Reach Middle Little Sioux Reach Lower Little Sioux Reach	Present alignment obtained by 1959
Upper Little Sioux Middle Little Sioux Lower Little Sioux	Present alignment obtained by 1959
Bullard	Present alignment obtained in 1961
Soldier	Alignment completed in 1962
Peterson Cutoff	Alignment established in 1957

TABLE 2. CHANNEL ALIGNMENT HISTORY BETWEEN SIOUX CITY & OMAHA

BEND (downstream from Sioux City)	DATE OF COMPLETED REALIGNMENT
Upper Sandy Point Middle Sandy Point Lower Sandy Point	Made into one bend. Present alignment obtained by 1959
Tysons Bend	Alignment established by 1959
California Cutoff	Completed in 1958
Upper Blair Lower Blair	Combined with part of DeSoto bend to form Blair-DeSoto bend in 1960
DeSoto Cutoff	Cutoff made in 1960
Bertrand-Harrison	Eliminated in 1960
Upper Calhoun Middle Calhoun Lower Calhoun	Essentially same alignment since 1950
Boyer bend to Manawa bend	Alignment has been stable since 1950

TABLE 2. CHANNEL ALIGNMENT HISTORY BETWEEN SIOUX CITY & OMAHA

Completion Date	Dam and Location	Capacity A.F.
1940	Fort Peck near Glasgow, Montana	18,900,000
1953	Fort Randall near Lake Andres, S. Dakota	5,700,000
1955	Garrison Dam near Garrison, N. Dakota	24,200,000
1955	Gavins Point near Yankton, S. Dakota	520,000
1962	Oahe Dam near Pierre, S. Dakota	23,500,000
1964	Big Bend Dam near Chamberlain, S. Dakota	1,910,000

TABLE 3. MISSOURI RIVER DAM CHRONOLOGY

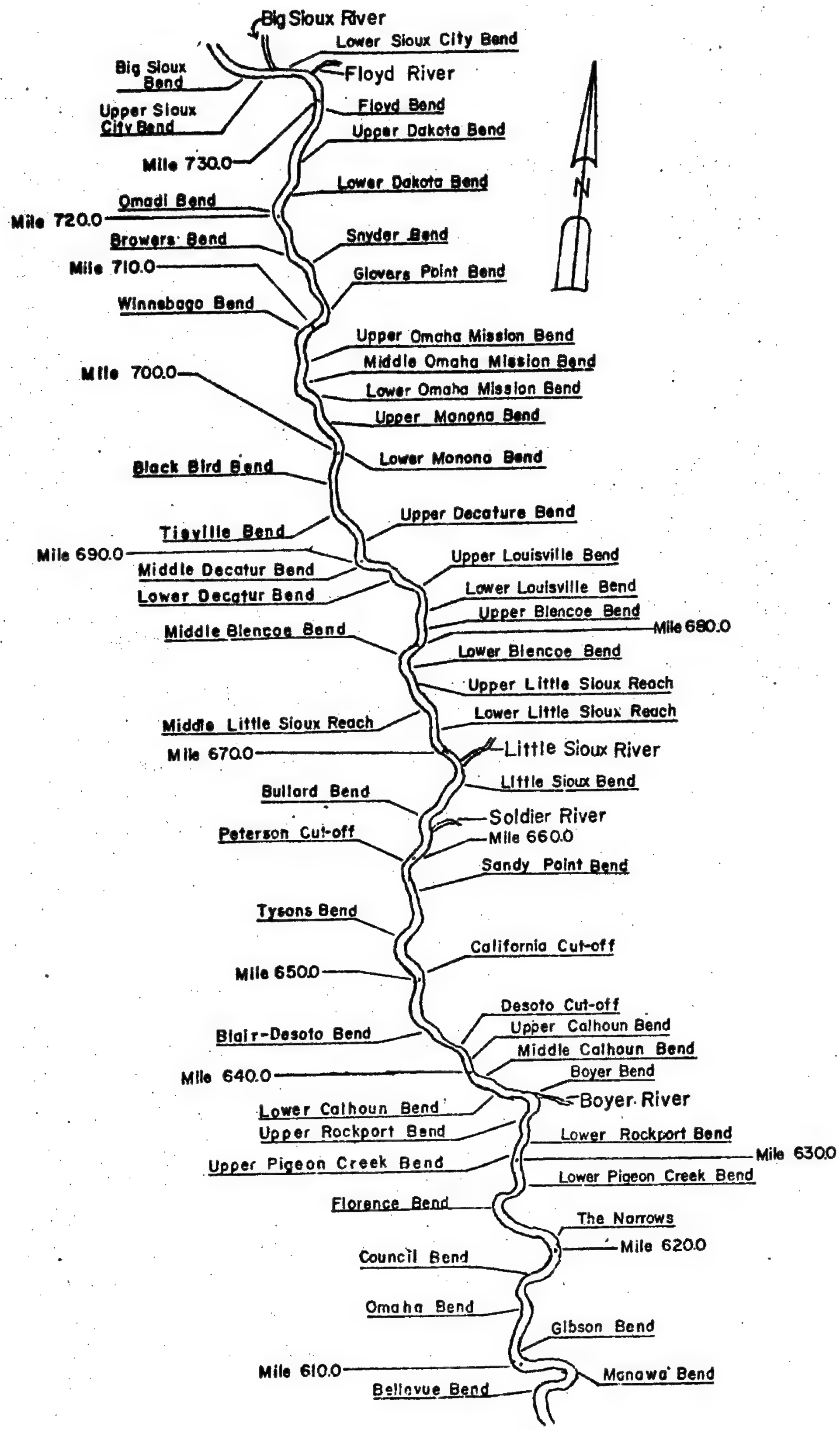

FIGURE 2. LOCATION MAP FOR MISSOURI RIVER BETWEEN SIOUX CITY, IOWA & OMAHA, NEBRASKA

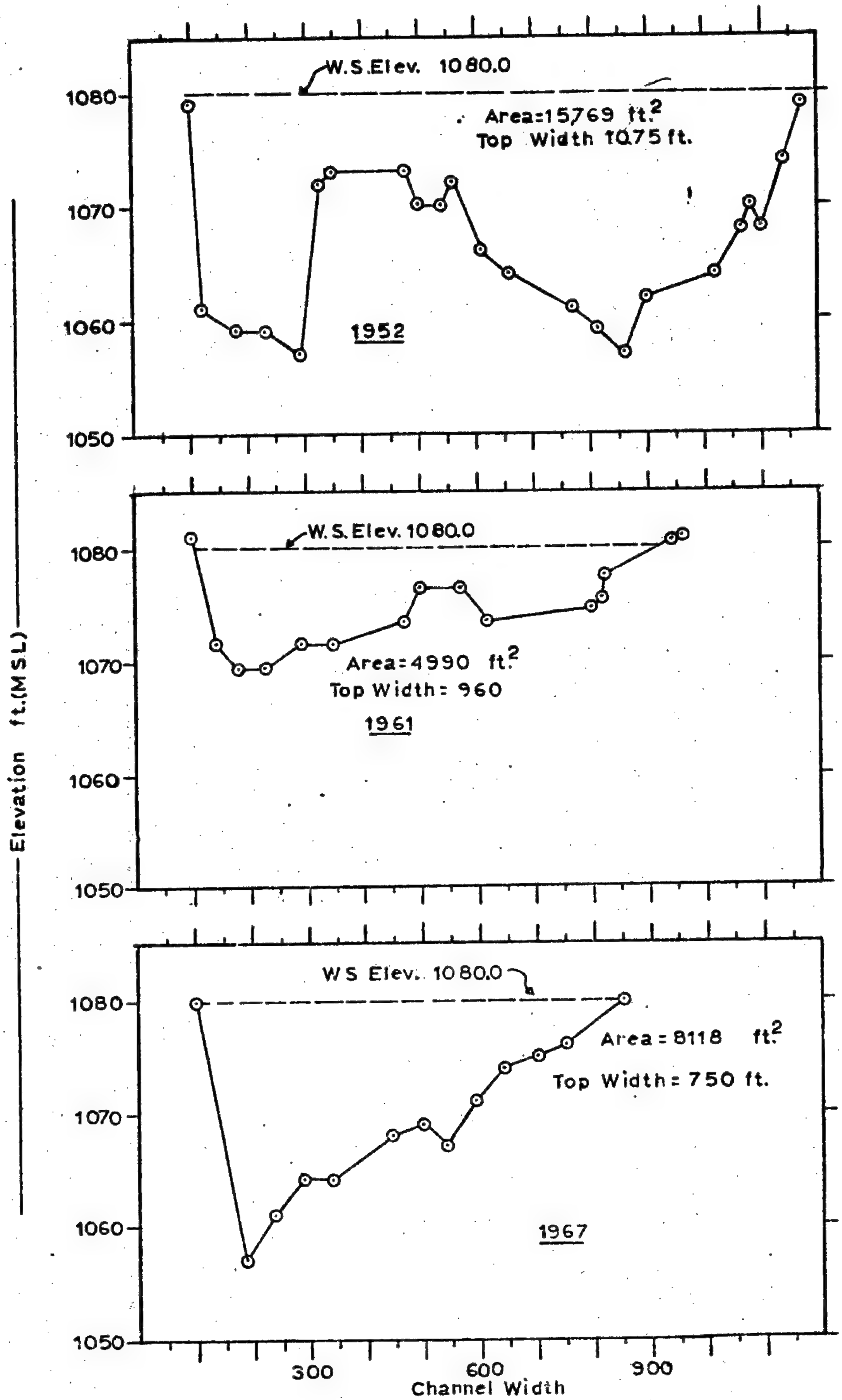

FIGURE 3. CHANNEL CROSS SECTION HISTORY AT RIVER MILE 731.7

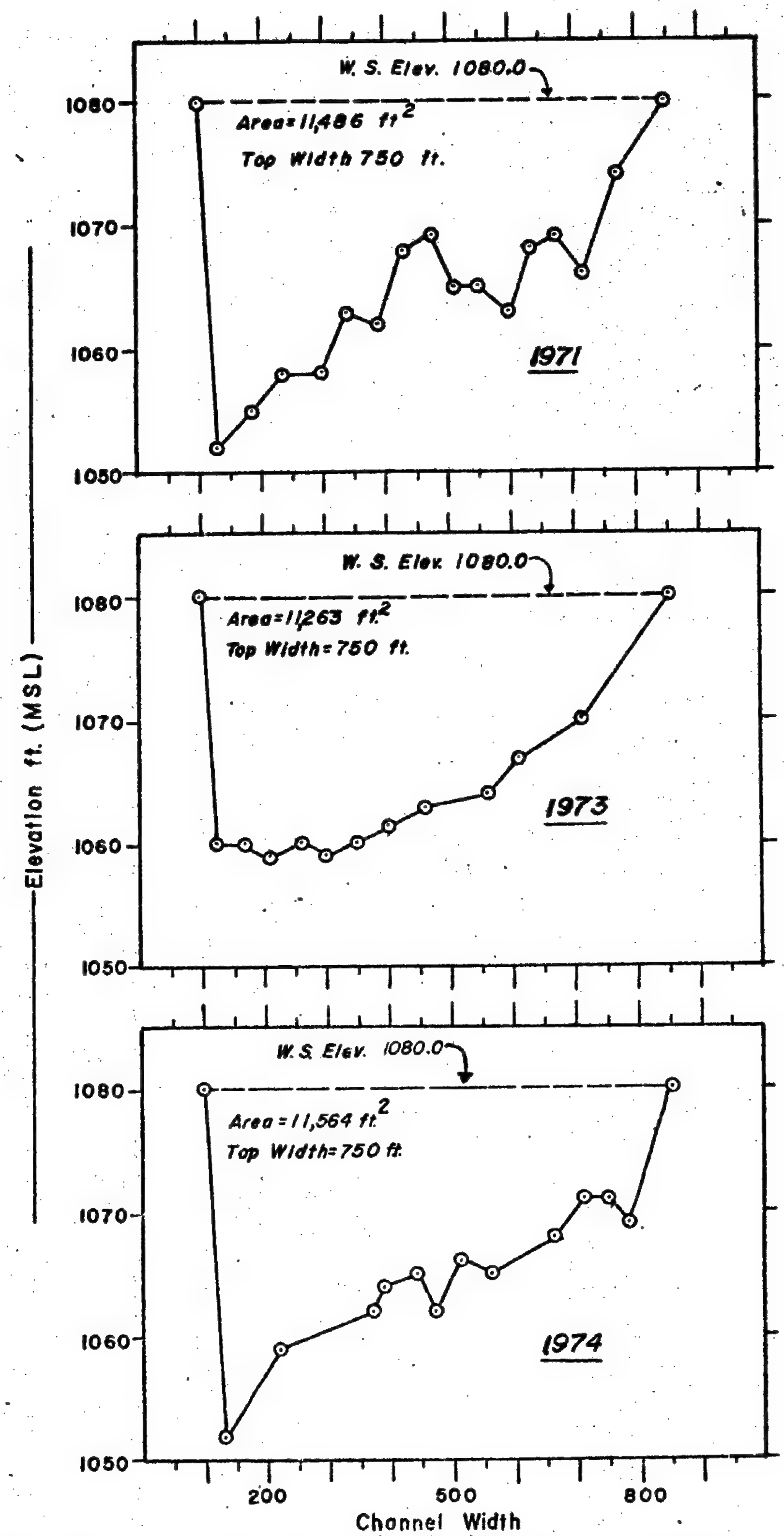

FIGURE 3. CHANNEL CROSS SECTION HISTORY AT RIVER MILE 731.7

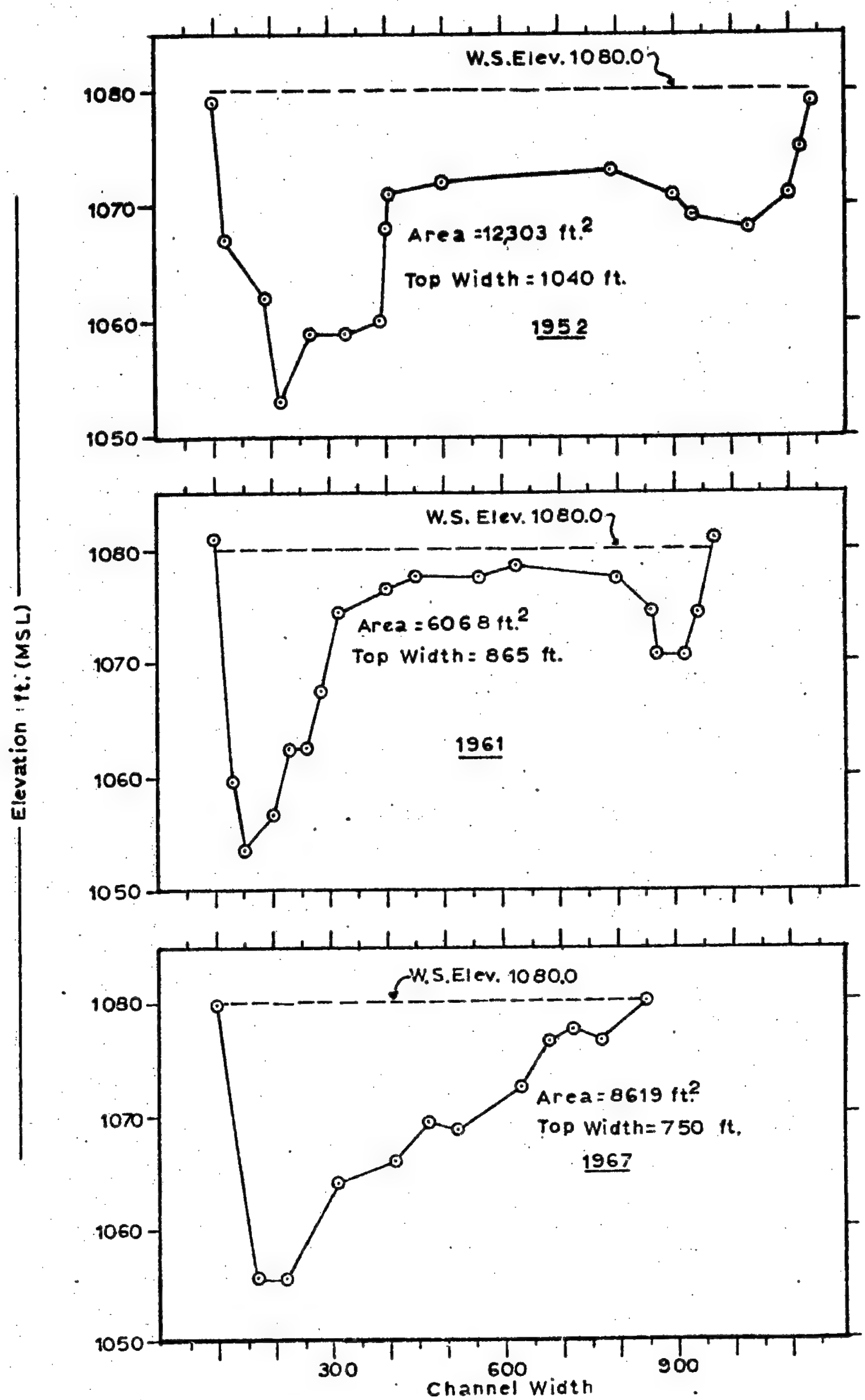

FIGURE 4. CHANNEL CROSS SECTION HISTORY AT RIVER MILE 731.49

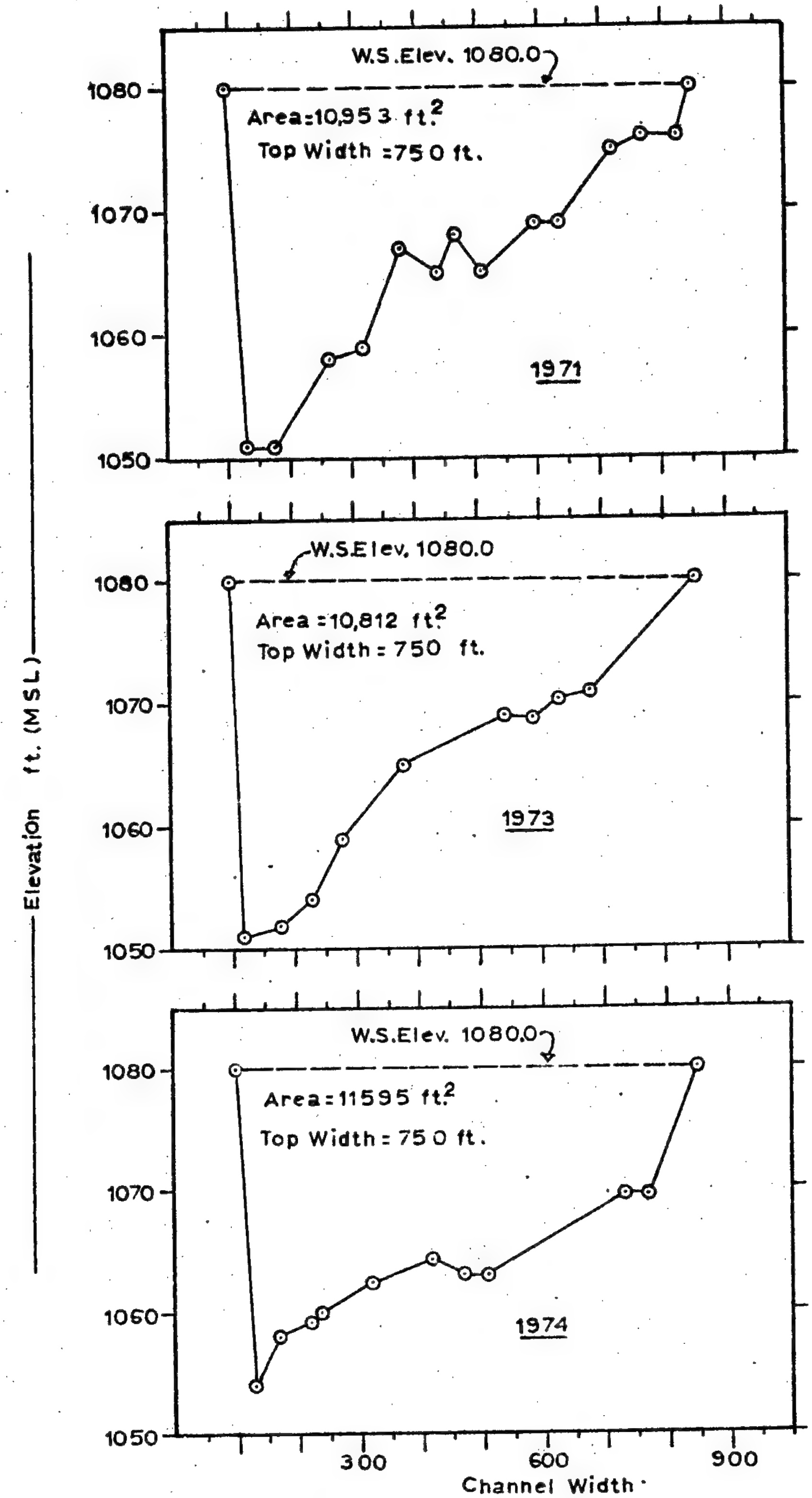

FIGURE 4. CHANNEL CROSS SECTION HISTORY
AT RIVER MILE 731.49

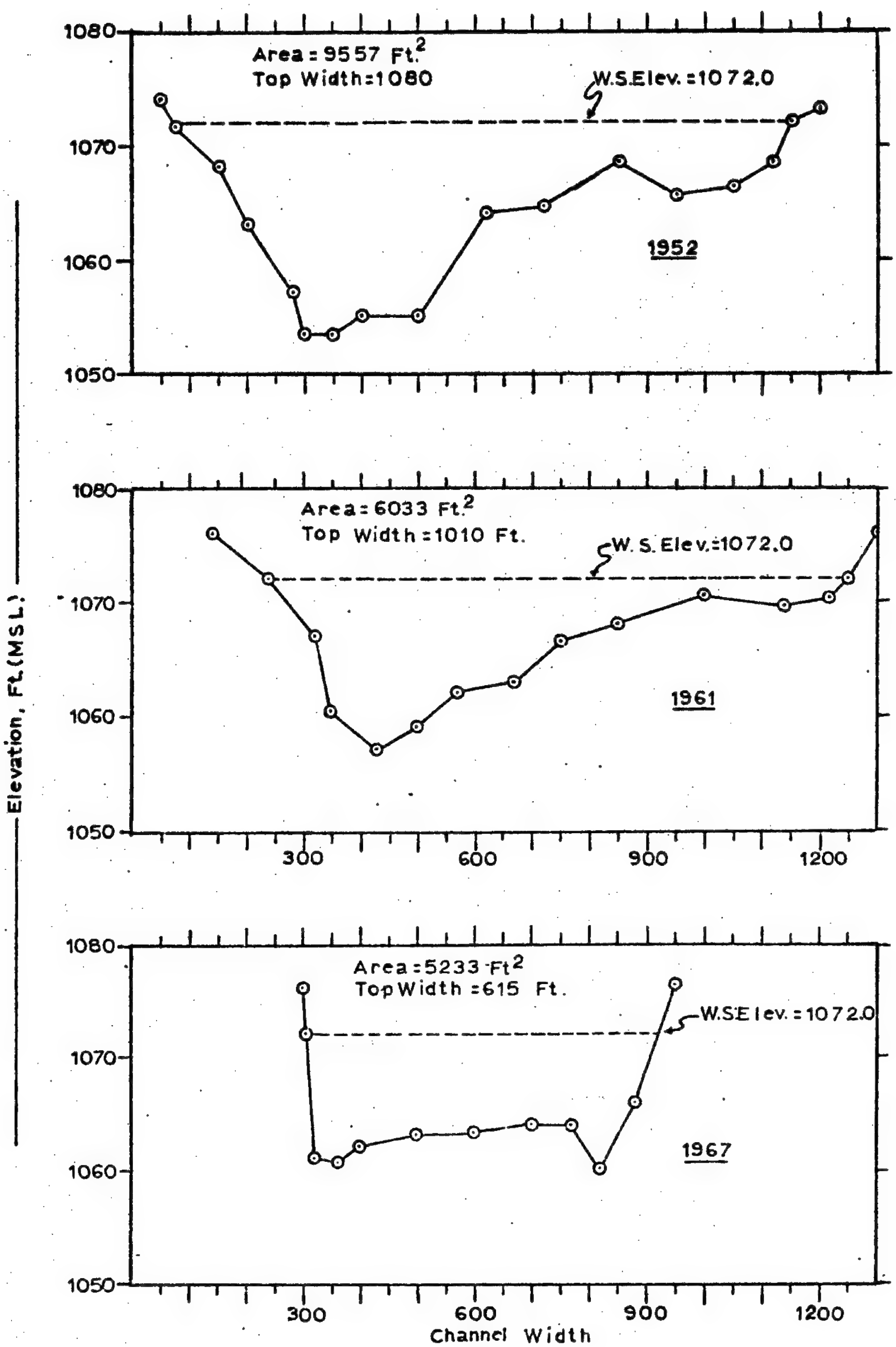

FIGURE 5. CHANNEL CROSS SECTION HISTORY
AT RIVER MILE 727.9

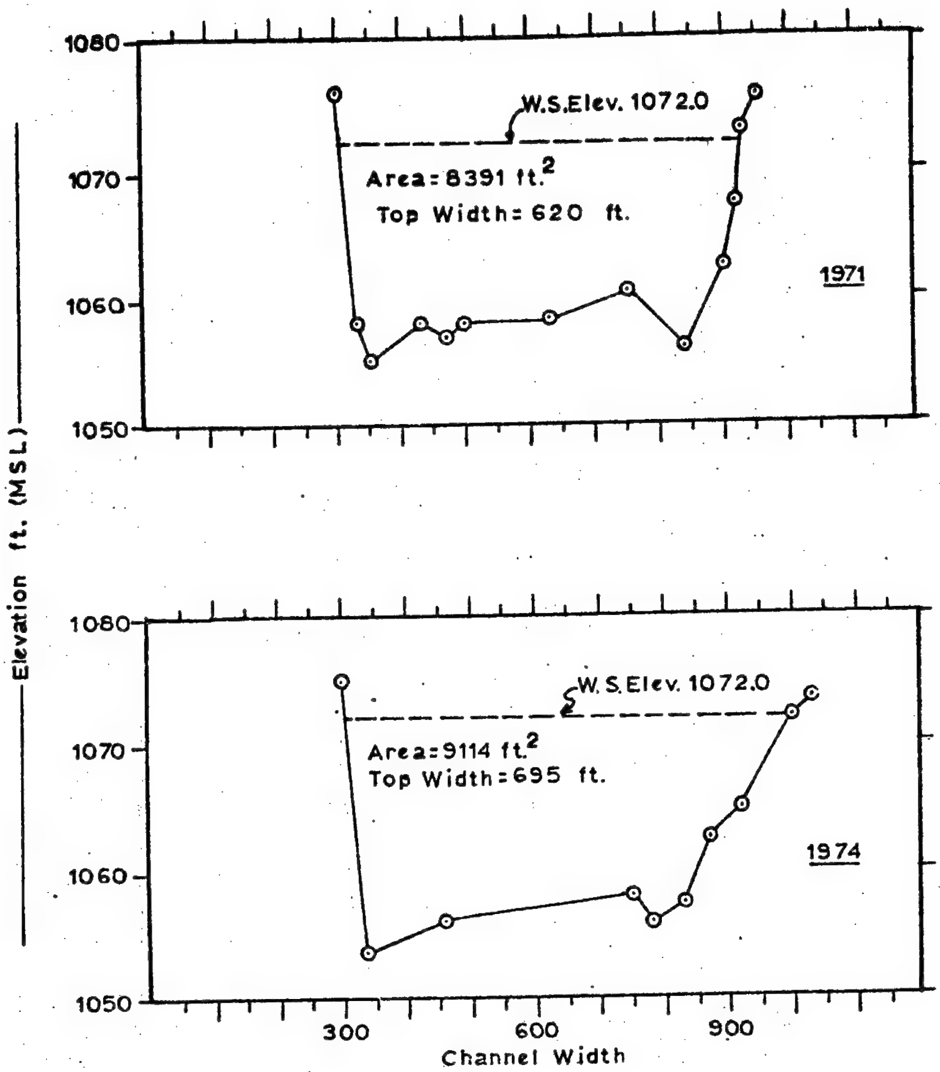

FIGURE 5. CHANNEL CROSS SECTION HISTORY AT RIVER MILE 727.9

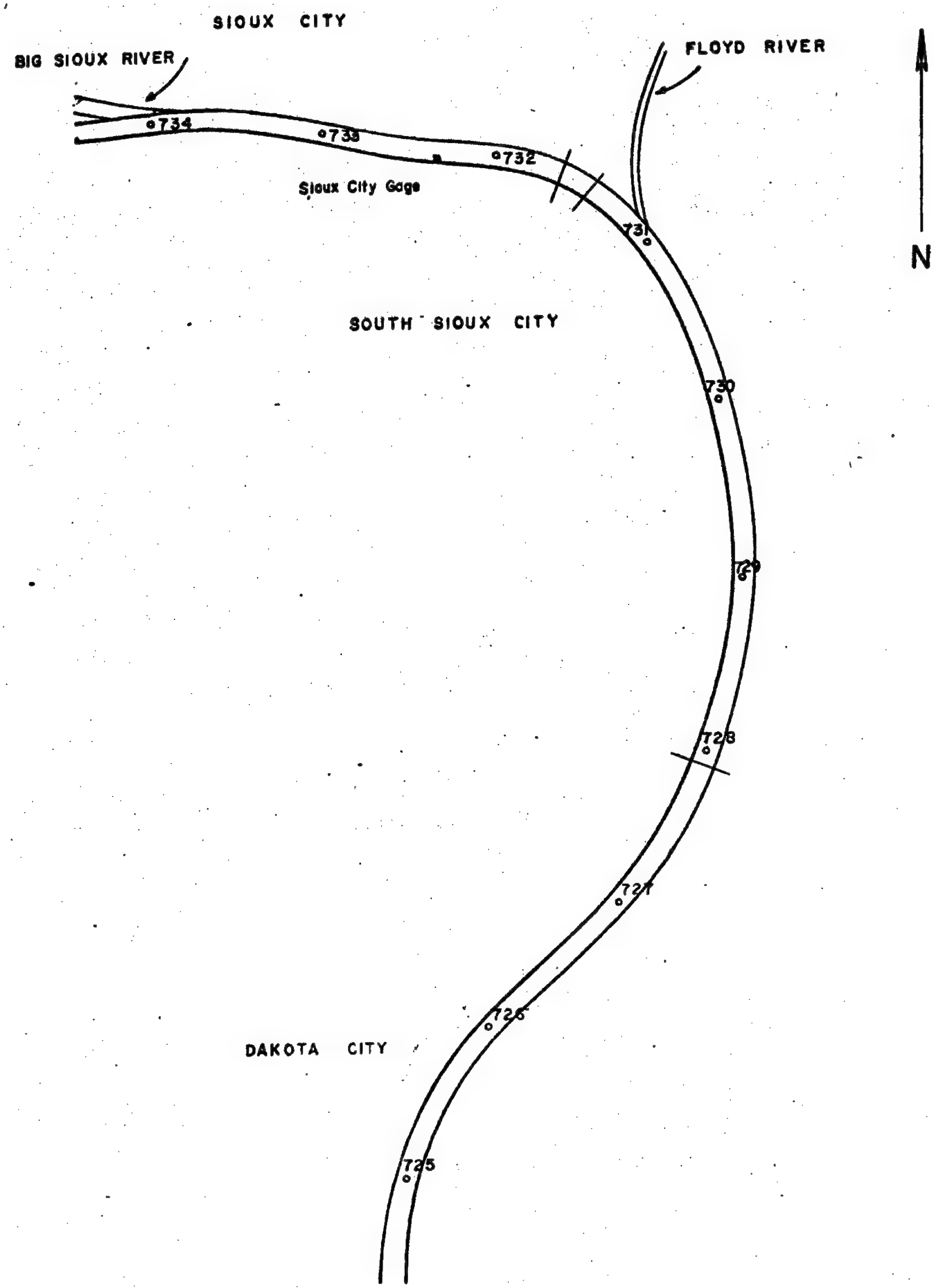

FIGURE 6. LOCATION MAP NEAR SIOUX CITY, IOWA

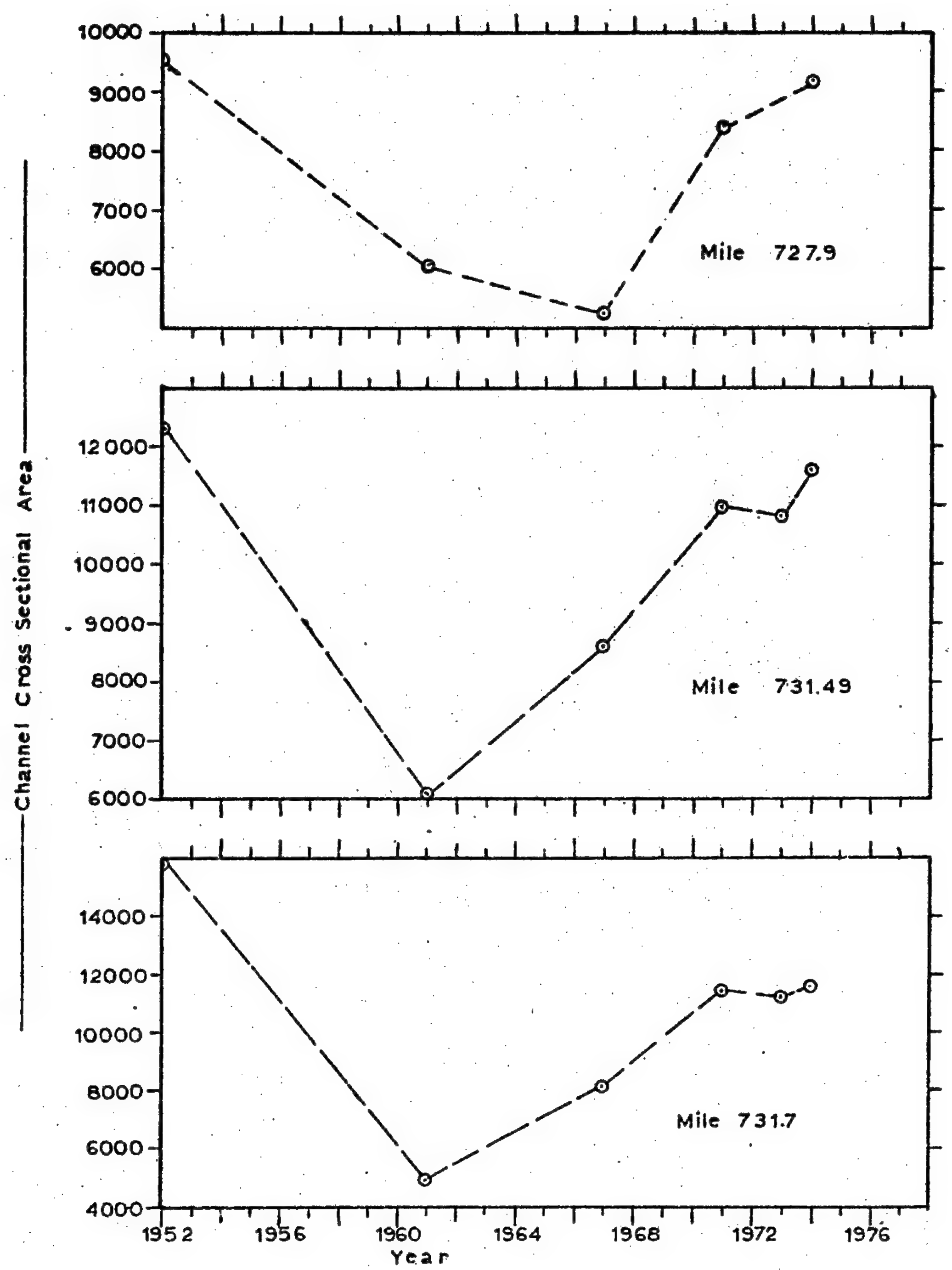

FIGURE 7. CHANNEL CROSS SECTIONAL AREA OF MISSOURI RIVER AT SIOUX CITY, IOWA

channel near Sioux City. After the flood, and up until the late 1960's, the channel bed rose in elevation as seen in Figures 3 through 5. Degradation below Gavins Point Dam since 1955 and subsequent deposition in reaches downstream built up the bed elevation during this period. Since 1967, the channel cross-section has increased in area and assumed more the appearance of a rectangular channel than that of a typical bend with a point bar. The area increase and change of channel shape are a result of high flows and relatively small sediment inflows, as will be discussed in following sections.

WATER SURFACE SLOPES

The slope of the water surface of the Missouri River was recorded at various time since 1952 for a condition of constant discharge for the reach between Ponca, Nebraska, to Omaha, Nebraska. Figure 8 shows the change in water surface slope both locally at Sioux City, Iowa, and over the entire reach between river miles 753.7 and 626.5 for the period being studied. The slope was greatly increased between 1952 and 1958 both over the long reach and locally. Since 1958 the reach from Ponca to Omaha has reduced the slope, which would be expected because of the scouring in the upstream areas of the reach. Locally, the reach continued to increase its slope until 1974. This does not imply that the local reach is aggrading, but that the lower end of the reach has degraded more than the upper end over the years.

SEDIMENTATION CONSIDERATIONS

The amount and size of sediment in a river affects the stage-discharge relationship in many ways. A change in the size or amount of sediment carried by a stream can cause changes in the channel bed form, the slope, the transport capability, etc., all of which have an influence on the stage-discharge relationship of a river.

The Missouri River in the vicinity of Sioux City, Iowa, has experienced a large change in its sediment properties since 1950. The most noticeable change is in the amount of suspended sediment carried in the reach from Yankton, South Dakota, to Omaha, Nebraska. Suspended sediment data is available at Yankton, Sioux City, and Omaha which show a large reduction in suspended sediment following the construction of Gavins Point Dam, which began in 1952 and was completed in 1955. Table 4 gives the annual suspended sediment load, in tons, at the 3 locations just mentioned. For the location at Yankton,

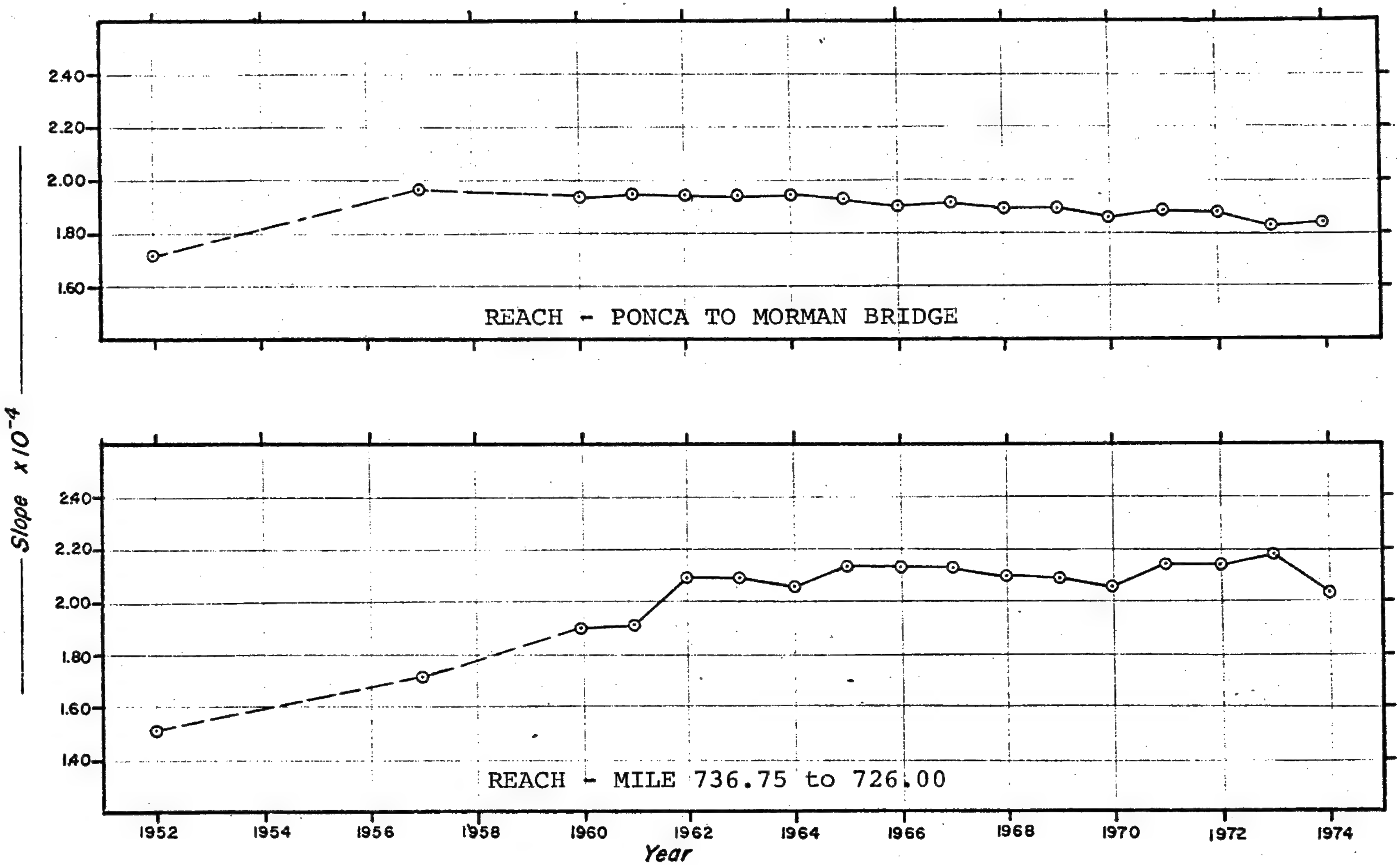

FIGURE 8. MISSOURI RIVER CHANNEL SLOPE, DISCHARGE OF 30,000 cfs

	Yankton	Sioux City	Omaha
1940	49,708,160		78,339,700
41	139,040,400		139,469,200
42	201,335,530		230,421,700
43	149,372,550		179,617,700
44	230,300,900		251,678,300
45	89,846,800		156,537,800
46	92,324,530		109,101,600
47	169,289,570		176,173,920
48	138,191,700		150,074,600
49	102,229,930		120,558,450
1950	147,674,220		159,551,910
51	108,940,000		219,458,870
52	174,534,500		157,962,850
53	58,811,400		80,535,400
54	26,752,870		37,292,590
55	8,942,470	12,134,530	25,492,410
56	4,389,480	14,148,090	23,312,190
57	1,740,960	8,047,150	27,992,230
58	1,258,600	7,306,160	19,104,800
59	1,611,350	10,642,000	28,803,650
1960	910,220	14,073,900	30,889,590
61	1,113,600	6,522,800	25,623,900
62	847,753	12,408,400	43,527,450
63	1,072,475	6,957,190	30,158,970
64	1,326,536	7,949,770	26,254,400
65	1,071,280	9,226,770	36,602,400
66	1,232,170	11,791,220	25,651,100
67	1,009,850	13,336,260	31,876,000
68	1,132,420	11,376,700	20,687,300
69	710,580	17,839,970	38,830,100
1970		14,871,960	20,887,300
71		23,682,700	27,975,560
72		16,265,800	28,488,300
73		8,842,530	20,338,690

TABLE 4. YEARLY SUSPENDED SEDIMENT LOAD AT YANKTON, S. DAKOTA, SIOUX CITY, IOWA, AND OMAHA, NEBRASKA.

South Dakota, the average annual suspended sediment load was decreased from 137,906,830 tons per year to 6,702,000 tons per year. The latter value represents the yearly average load from 1953 to present and is 4.9 percent of the yearly average before 1953. Similar figures for the Missouri River at Omaha are a decrease from 163,765,123 to 32,507,911 tons per year. This is 19.9 percent of the yearly average suspended sediment load prior to 1953 at Omaha. Although the data before 1955 are not available at Sioux City, Iowa, a comparable decrease in suspended sediment discharge probably occurred because Sioux City lies between Yankton and Omaha.

The same figures of average yearly suspended sediment loads before and after 1953 show that the suspended sediment load at Yankton, South Dakota was 84% of the load at Omaha, Nebraska before 1953. Since 1953 the load at Yankton is only 21% of that figure for Omaha, which suggests that the Missouri River picks up a greater percentage of its suspended sediment loads in the reach below Gavins Point dam than it did before 1953. However, the average total amount of increase in yearly average suspended sediment load from Yankton to Omaha before 1953 was only 25,858,293 tons per year between the two points. The difference in the yearly average loads between the same locations since 1953 is 25,805,911 tons per year, or very near to the difference prior to construction of Gavins Point dam. So the amount of suspended sediment load picked up between Yankton and Omaha remained essentially the same before and after construction of Gavins Point dam, but the percentage of suspended sediment load increased because of the relatively small quantities involved subsequent to the building of Gavins Point dam.

The records of the size of bed material in the Missouri River at Yankton, Sioux City, and Omaha indicate a decrease in the amount of suspended sediment as well as a possible increase in the sediment transport capacity of the river. Table 5 shows a definite increase in the average yearly bed material D50 size at Yankton, South Dakota and Sioux City, Iowa. The average yearly sizes are an average of the samples taken in the water year which ends in September of that year. The increase happened in 1955 just after the closing of Gavins Point dam. Because the dam impounded a large percentage of the sediment load normally in the water, the clearer water was able to transport more of the bed material, thus increasing the size of material left on the bed. The river picked up less and less bed

	Yankton	Sioux City	Omaha
1950	359		718
51	348		313
52	456		782
53	359		219
54	321		302
55	966	244	217
56	802	263	257
57	1003	295	228
58	421	271	217
59	509	277	225
1960	586	275	289
61	491	266	215
62	556	287	226
63	523	293	213
64	457	292	233
65	450	329	248
66	418	296	250
67	430	308	237
68		311	248
69		296	280
1970		321	287
71		318	239
72		341	243

TABLE 5. WATER YEAR AVERAGE BED MATERIAL SIZE

D_{50}, mm x 1000

material as it traveled downstream. The recording station at Omaha shows no increase in the bed material sizes over the years.

The sediment data reveal the large change in sediment load carried through the reach between Yankton and Omaha which is due to construction of Gavins Point Dam. The effects of these changes on the river at Sioux City have been felt in the form of degradation of the reach. Further analysis of the effects of the sediment on the Sioux City reach is given in the Analysis.

FLOW HISTORY OF MISSOURI RIVER & TRIBUTARIES

The flows of the Missouri have produced several significant events since 1950 which relate to the stage-discharge relationship at Sioux City, Iowa. The flow records of the Missouri River since 1950 at Yankton, Sioux City, and Omaha are given in Tables 6, 7, and 8, as taken from U.S.G.S. Water Supply Papers.

In 1952, a flood of 441,000 cfs occurred at Sioux City and passed through Omaha at 396,000 cfs. This flood is the largest on record at both locations. The magnitude of the flood suggests that it is probably greater than the project design flood since new channels were formed and many training structures were breached and left in the flood plain of the new channel alignment. Channel areas were enlarged to the size shown in the cross-sections of Figures 3 through 5. Previous research on the nature of geometric equilibrium in alluvial bed streams has indicated that particular geometric characteristics of an alluvial channel, such as cross-sectional area, slope, bend radii, etc., are closely related to a particular discharge which has been labeled as the "channel forming discharge." [1] The flood flow of 1952 was the channel forming discharge which determined the subsequent alignment and properties of the river.

The flow data at Sioux City also show that the mean yearly discharges averaged 21,600 cfs from 1954-1965 and then increased to an average of 32,143 cfs from 1966-1974, or the period which is called the flow regulation period. The magnitude of maximum discharges averaged

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[1] Stevens, Michael A., Simons, Daryl B., and Richardson, Everett V., "Nonequilibrium River Form," Journal of the Hydraulics Division, ASCE, Vol. 101, No. HY5, Proc. Paper 11334, May 1975, pp. 557-566.

Year	Maximum Discharge, cfs	Mean Discharge, cfs
1951	134,000	33,100
52	480,000	42,730
53	112,000	29,260
54	38,600	23,160
55	38,500	22,340
56	47,000	23,370
57	38,600	18,940
58	35,300	19,720
59	33,900	20,080
1960	34,700	17,520
61	31,800	19,470
62	35,900	14,490
63	33,800	20,550
64	34,400	20,940
65	35,000	20,290
66	35,800	25,420
67	39,600	25,000
68	41,200	28,080
69	56,000	30,580
1970	50,000	32,130
71	52,500	36,300
72	54,500	38,240
73	51,200	29,630
74	37,400	27,250

TABLE 6. YEARLY MAXIMUM AND MEAN DISCHARGE.

MISSOURI RIVER AT YANKTON, S. DAKOTA

Year	Maximum Discharge, cfs	Mean Discharge, cfs
1951	152,000	37,830
52	441,000	47,250
53	109,000	31,280
54	51,300	24,870
55	56,200	22,250
56	38,900	23,640
57	36,200	19,770
58	39,500	20,150
59	33,600	20,610
1960	101,000	21,390
61	32,700	20,880
62	71,600	20,030
63	34,400	21,210
64	37,400	21,760
65	35,600	22,650
66	38,200	27,420
67	37,100	26,430
68	38,300	28,250
69	77,700	34,270
1970	51,200	33,510
71	69,800	38,320
72	55,700	40,750
73	54,100	32,230
74	40,000	28,110

TABLE 7. YEARLY MAXIMUM AND MEAN DISCHARGE

MISSOURI RIVER AT SIOUX CITY, IOWA

Year	Maximum Discharge, cfs	Mean Discharge, cfs
1951	152,000	43,050
52	396,000	49,150
53	112,000	33,350
54	87,400	26,560
55	51,500	23,800
56	42,600	24,040
57	59,000	20,490
58	45,400	20,790
59	57,000	21,520
1960	120,000	23,800
61	41,700	22,790
62	115,000	24,270
63	61,700	22,840
64	68,900	22,740
65	69,800	25,730
66	61,800	28,480
67	68,400	28,010
68	53,000	28,510
69	100,000	37,620
1970	51,600	34,350
71	79,700	40,260
72	66,800	42,300
73	58,600	35,220
74	47,900	30,170

TABLE 8. YEARLY MAXIMUM AND MEAN DISCHARGE

MISSOURI RIVER AT OMAHA, NEBRASKA

Year	Maximum Discharge, cfs	Mean Discharge, cfs
1951	28,800	1,822
52	33,000	2,090
53	21,800	1,141
54	21,700	1,093
55	4,940	312
56	1,840	191
57	19,400	728
58	1,120	238
59	8,430	242
1960	49,500	1,402
61	9,050	560
62	54,300	2,230
63	1,650	398
64	2,540	307
65	21,000	1,180
66	16,500	630
67	5,300	543
68	635	125
69	80,800	2,489
1970	7,380	822
71	6,900	734
72	10,100	1,251
73	12,100	1,061
74	1,830	348

TABLE 9. YEARLY MAXIMUM AND MEAN DISCHARGE

BIG SIOUX RIVER AT AKRON, IOWA

58,083 cfs from 1969-1974 and 36,833 cfs for the 6 years before 1969. The data show that the period from 1969 onward had higher flood and average discharges than did the period from 1953-1969. The same general results are present for Yankton and Omaha.

Table 9 shows the flow records of the Big Sioux River at Akron, Iowa.

Because the Big Sioux River enters the Missouri River just upstream of the gaging station at Sioux City, some local effects due to the Big Sioux flows may have altered the stage-discharge relationship at Sioux City. Since 1969 the Big Sioux River has experienced the largest flood of its record of 80,800 cfs. The period since 1969 has also had relatively high mean discharges as seen in Table 9. The increased flow quantities would add to the scouring of the Missouri River at the confluence with the Big Sioux and thus affect the rating curve at Sioux City.

ANALYSIS

In the time period of 1950 to the present, many of the alterations to the Missouri River, in the forms of channel straightening, bank protection and dam construction, have influenced the response of the river. River response can be categorized as relating to four factors which determine the limits of response. The four factors are geology, hydrology, river plan and cross-sectional geometries, and hydraulic properties. One of the overall effects of the interaction of the four factors mentioned has been a change in the stage-discharge relationship of the Missouri River at Sioux City, Iowa. Geological changes are largely due to the differences in bank materials of the river channel. The banks are no longer as susceptible to erosion and caving because of the river training structures which have been installed over the years. A large change in the magnitude of water and sediment discharges in the river due to regulation by dams has changed the hydrologic characteristics of the Missouri River at Sioux City. Geometrically, the river has been changed from a braided channel to a single sinuous channel. The large amount of channel modification altered the hydraulic characteristics by increasing flow depths, velocities, and slopes.

The available data on the Missouri River since 1950 clearly show which factors have played a major part in the shift of the rating curve at Sioux City, Iowa. Channel straightening has shortened river length, thus increasing slope and sediment transport capacity. An increase in sediment transport capacity has been related to some degradation of the river bed near Sioux City. Bank protection has decreased the amount of sediment carried by the river as a product of bank caving and dam construction has captured all of the sediment which the river has carried above any of the existing reservoirs. The decrease in sediment available to the river as a result of bank protection and dam construction has made some transport capacity available. The available transport capacity has then focused on sediment within the river channel and consequently has lowered bed elevation and generally increased channel size around Sioux City. The alterations which the river has undergone in seeking to reestablish an equilibrium between slope, discharge and sediment transport capacity have resulted in a lowering of stage, relative to mean sea level, in the Sioux City area.

The readjustment of the Missouri River following the changes in the factors just mentioned has occurred

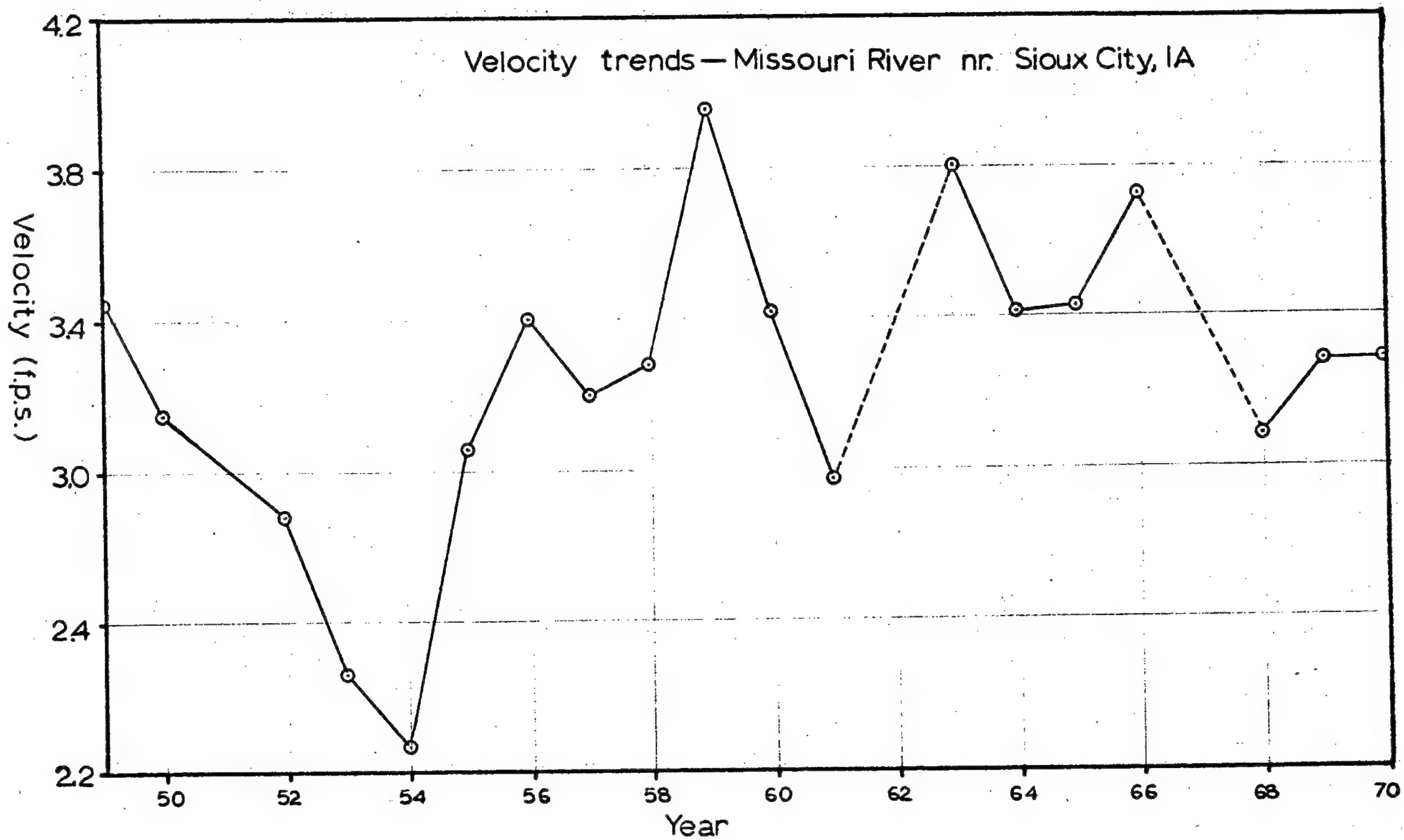

FIGURE 9. MISSOURI RIVER VELOCITY TRENDS

in both short and long term time frames, as the Missouri River still seems to be adjusting to reach a state of equilibrium of flow conditions.

The shift in the stage-discharge relationship at Sioux City, Iowa, has resulted in a 5-8 foot lowering in stage for a constant discharge in the period from 1960 to the present. Figure 1 shows that the rate of shift increased around 1968. The reasons for the shift are found in the historical records of the Missouri River from 1950 to the present.

Probably the major influence on the flow characteristics of the Missouri River has been the construction of dams on the river. Construction of Garrison, Oahe, and Gavins Point Dams were completed in 1955, 1962 and 1955 respectively. Also, during the years from 1953 to 1963, the alignment of the river was completely "overhauled" resulting in a narrower sinuous channel.

Establishment of the present alignment shortened the river mileage 10.6 miles from 123.9 miles to 113.3 miles between the present mileage points of 732.2 (Sioux City) and 619.0 (Omaha). The shortening process occurred continuously throughout the 10 year period. The date the cutoffs were finished is shown in Table 2. The expected river response to this relatively large reduction in length, or increase in slope, is to degrade to reestablish a state of equilibrium. This degradation is shown in the cross-section chronology of Figures 3 through 5. Consequently, the stage for a given discharge is lowered.

Construction of Gavins Point Dam also affected the degradation of the channel at Sioux City. The data show a large reduction (95%) in the suspended sediment load at Yankton subsequent to the construction of Gavins Point Dam. This reduction increases the transport capacity of the water and causes bed material, which otherwise would not have been transported under previous conditions, to be moved by water with a lower sediment concentration. This phenomenon is supported by the fact that the bed material data for the period show larger sizes after 1955 at Yankton and Sioux City which result from an increased transport rate. The result of the increased transport capacity is degradation, and in this case, a lowering of the stage for a given discharge at Sioux City.

Another result of construction was the narrowing of the river channel at Sioux City by 300-500 feet in 1965. This concentrated the flows, increased the flow depths, velocity, and consequently the transport rate. The result is analagous to that of the dam and channel shortening.

Another qualitative look at the data is given using Lane's relation (1955) which states that:

$$QS \simeq Q_s D_{50}$$

where

Q = water discharge
Q_s = sediment discharge
S = channel slope
D_{50} = median diameter of bed material

Rearranging, using $S = \frac{d}{L}$ where d is the change in channel elevation between two points and L is the channel length between these points gives:

$$Qd \simeq Q_s D_{50} L$$

which indicates that the discharge-elevation product is proportional to sediment discharge, bed material size, and channel length.

In the case of the Missouri River, construction of the dams and channel improvement decreased Q_s and L to a large extent. To compensate, the elevation change had to be largely reduced to maintain the proportionality. The water discharge, Q, showed an increasing tendency, which compounded the transport effects, and D_{50} increased somewhat due to the armoring effect of picking up new sediment. A significant amount of degradation would be expected to compensate for the sediment discharge and length changes.

As previously mentioned, an increasing trend in discharge passing the cross-section has also affected the rate of change in the stage-discharge relationship at Sioux City since 1968. The mean yearly discharges averaged 32,143 cubic feet per second (cfs) since 1966 and only 21,600 cfs from 1954 to 1965. The peak flows averaged 58,083 cfs since 1969 and only 36,833 cfs in the six years before 1969. The large flows in the period since 1966-1969 increase the sediment transport capability and subsequently cause additional degradation. Continuously larger flows would help account for the increase in channel area shown by Figure 7. Again looking at Lane's relation, assuming the Q_s, L, and D_{50} remain constant, any increase in Q would require a decrease in d to maintain the proportionality with the right hand side of the equation which is constant.

Some local effects in stage lowering may be attributed to the Big Sioux River which enters the Missouri River just above the gage at Sioux City. The large flows of late would help increase the rate of bed degradation.

Overall, the events which have occurred on the Missouri River have combined to cause degradation in the reach at Sioux City, Iowa. This occurrence has caused the significant lowering of stage for a given discharge.

CONCLUSIONS

The causal factors related to the lowering of the stage in the stage-discharge relation for the Missouri River at Sioux City, Iowa from five to six feet are:

(1) Construction of the dams upstream of Sioux City, Iowa. In particular, the closing of Gavins Point Dam in 1956, which has trapped all the sediment coming from the upper reaches of the Missouri River and has changed the time sequence of the flow. The clear water releases from Gavins Point Dam have resulted in the river picking up a new sediment load downstream of the dam with a consequent lowering of the channel bed. This channel lowering will continue until such a time as the bed material becomes coarser and the capacity of the stream to transport bed material through the reach is decreased so that it equals the sediment inflow from the tributaries.

The change in the discharge hydrograph whereby large yearly peak flows no longer occur, high flows are sustained for a longer time during the summer navigation season, low flows are larger during the winter period, and sediment inflow from the tributaries is small, helps contribute to the degradation of the channel. In addition, the larger-than-normal runoff from the system the last few years has further increased the discharge in the river during the summer months and increased the rate of degradation, but probably not to the ultimate magnitude of possible degradation.

(2) Modification of the river from a braided channel to a sinuous channel of relatively constant width also would cause degradation of the channel. One reason is that confining of the flow increases the depth and velocity, thus increasing transport capacity; another is the stabilizing of the banks which removes them as a source of sediment; and a third reason is the increase in slope. However, the degradation resulting from the channel change is secondary to the degradation that results from the impoundment of the sediments by the upstream reservoirs. That is, channel modifications would cause some lowering of the bed in this reach but the magnitude of this degradation is less than that which is caused by the trapping of the sediment by the upstream reservoirs. With both channel modification and dam construction,

the principle influence of the channel modifications is on the rate of degradation but not the magnitude. Even if dams were constructed with no channel modifications, the bed of the Missouri would still reach approximately the same ultimate elevation as it would with construction of both dams and sinuous channel. The only difference is that the river would then work the full valley width and its lowering would take a much longer period of time.

(3) There may be other causal factors in the degradation of this reach of the Missouri River such as increase in flow experienced by the main stem of the Missouri River and its tributaries the past few years or the braided condition of the Missouri River between Yankton, South Dakota and Ponca, Neb.which at this time decreases the sediment inflow into the Sioux City reach. But these factors are outweighed by the effects of dam construction which removes the source of sediment to this reach of the Missouri River whereby the river re-establishes its sediment discharge by scouring the bed.

RECOMMENDATIONS

At the time of this study it does not appear that the Missouri River has reached a stage of equilibrium between the amount of sediment moving into the reach at Sioux City, Iowa and the amount of sediment moving out. That is, degradation is still continuing. Ultimately the river will reach some sort of equilibrium between the amount of sediment coming from the tributaries, the size of the bed material, and the transport capacity of the reach which determines the amount of material leaving. At this time the stage-discharge relation would fluctuate around some mean elevation. There may be some geologic controls such as bed rock, glaciers, gravel, or till that would limit scour. There are not enough data available to predict the stable equilibrium condition for this reach of the Missouri River at this time. The following are recommendations for data collections which would be needed to determine the equilibrium river conditions, or to determine methods of controlling of the degradation.

(1) Continue with the present data collection program which furnish data for the total river system.

(2) Determine the characteristics of the bed material in the reach of the Missouri River at Sioux City by taking in depth core samples.

(3) Take cross sections at 1000 ft through the reach at different discharges.

(4) Establish suspended sediment measurement stations on the Big Sioux River, Boyer River and other major tributaries up and downstream of Sioux City, Iowa.